

# TUNABLE MICRORESONATOR ON AN INSULATING BEAM DEFORMABLE BY THE DIFFERENCE IN THERMAL EXPANSION COEFFICIENTS

## BACKGROUND OF THE INVENTION

### Field of the Invention

5                   The present invention relates to the field of piezoelectric microresonators.

### Discussion of the Related Art

                  A piezoelectric microresonator conventionally comprises a piezoelectric layer sandwiched between two conductive electrodes. Such a  
10   microresonator is likely to start resonating when the signal applied between its electrodes is at a determined frequency.

                  Apart from any external influence, the resonance frequency of a microresonator is set upon manufacturing, especially according to the thickness and to the nature of the piezoelectric layer. Now, for many circuits such as  
15   settable analog filters, it is desirable to be able to vary the resonance frequency of microresonators.

## SUMMARY OF THE INVENTION

                  An object of the present invention is to provide a tunable microresonator.

20                To achieve this object, the present invention provides a device comprising a resonator formed of a piezoelectric layer sandwiched between two metal electrodes, the resonator being laid on a suspended beam, the device comprising means for deforming said beam by the difference in thermal expansion coefficients.

According to an alternative of the device of the present invention, the means for deforming the beam comprise heating elements and one or several blocks in contact with the beam, the blocks being formed of a material having a thermal expansion coefficient different from that of the beam.

5                   According to an alternative of the above-mentioned device, the heating elements are placed within the beam.

                  According to an alternative of the device of the present invention, electrodes are placed in the beam opposite to other electrodes external to the beam, the electrodes being connected to a voltage source capable of biasing the  
10   electrodes to maintain the beam deformation.

                  According to an alternative of the above-mentioned device, the beam is placed above a cavity formed in a substrate, the external electrodes being placed in the cavity.

                  The present invention also provides an integrated circuit comprising  
15   a resonator such as that described hereabove.

                  The foregoing objects, features, and advantages of the present invention will be discussed in detail in the following non-limiting description of specific embodiments in connection with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

20                   Fig. 1 is a cross-section view of an embodiment of the device of the present invention at rest;

                  Fig. 2 is a cross-section view of the device of the present invention in a "deformed" state; and

                  Fig. 3 is a top view of the device of the present invention.

## 25   DETAILED DESCRIPTION OF THE INVENTION

                  The various drawings are not drawn to scale but are drawn to make clear various features of the invention.

The device of the present invention, shown in Figs. 1 and 2, comprises a resonator 1 laid on a beam 2 suspended on its two ends. Resonator 1 is formed of a stack of thin layers and comprises a piezoelectric layer 3 sandwiched between two conductive electrodes 4 and 5. Other materials that are well known in the industry could also be used for each of the layers 3, 4 and 5. Piezoelectric layer 3 is for example formed of aluminum nitride AlN and the electrodes are for example formed of aluminum, molybdenum, or platinum. Beam 2 is a thin strip of an insulating material, acceptable materials being any semiconductor insulator such as silicon nitride (SiN), silicon dioxide, a glass, TEOS, or other layer. Beam 2 is suspended above a cavity 10 formed in a substrate 11. The ends of beam 2 are laid on substrate 11 on either side of cavity 10.

As illustrated in Fig. 3, in top view, the lateral edges of beam 2 are spaced apart from the edges of cavity 10.

Substrate 11 may be formed of any type of material. In the case where the device of the present invention belongs to an integrated circuit, substrate 11 may be the passivation layer covering the interconnect network circuit or be the insulating layer separating the last and the penultimate circuit interconnect levels. In the case where the device is a discrete component, substrate 11 may be a silicon semiconductor wafer or an insulating layer, for example, silicon oxide, laid on a support wafer, for example, silicon.

According to an aspect of the present invention, the device comprises means for deforming beam 2 by the difference in thermal expansion coefficients. Resonator 1 being laid on the resonator beam, a deformation of beam 2 results in a deformation of the resonator. Now, the resonance frequency varies according to the deformation of resonator 1.

In the example of the device shown in Figs. 1 and 2, metal blocks 20 and 21 are laid on beam 2. Resonator 1 is placed at the center of the portion of beam 2 located above cavity 10. Blocks 20 and 21 are placed on either side of

resonator 1. Heating resistors 22 and 23 are placed under blocks 20 and 21 within beam 2. Heating resistors 22 and 23 are for example formed of a titanium nitride layer TiN and are supplied via connections not shown. Process steps for forming a cavity under a suspended beam having the components as shown in Figs. 1-3 are well known in the art and thus are not described herein since any of the many known ways are acceptable.

To best diffuse the heat generated by the heating resistors in beam 2 to metal blocks 20 and 21, the heating resistors preferably have in top view a width close to the beam width and extend over the entire beam area located under blocks 20 and 21. Further, the heat generated by heating resistors 22 and 23 being proportional to their resistance, their thickness can be reduced to a minimum.

To switch from the resting state to the deformed state, such as respectively illustrated in Figs. 1 and 2, an activation circuit, not shown, conducts current into heating resistors 22 and 23, which results in heating blocks 20 and 21 and beam 2. Since the aluminum of blocks 20 and 21 has an expansion coefficient greater than the silicon nitride of beam 2, blocks 20 and 21 lengthen more than beam 2. Accordingly, the beam ends slightly bulge upwards and the central portion of the beam bends downwards. During the deformation of beam 2, microresonator 1 laid on beam 2 progressively bends, its ends curving upwards.

In one embodiment, the beam 2 is flat across the cavity 10; in another embodiment, the beam 1 is formed with a slightly upward curve, as shown in Fig. 1. To have a great latitude of deformation of beam 2, and thus of resonator 1, beam 2 may have at rest a shape slightly bulged upwards, as shown in Fig. 1.

Generally, blocks 20 and 21 laid on beam 2 must be formed of a material having a thermal expansion coefficient different from that of beam 2 so that the block and beam assembly twists as the temperature increases. In the case where metal blocks 20 and 21 have a smaller thermal expansion coefficient than that of beam 2, it may be provided to place the blocks under beam 2.

Since the resonator's resonance frequency varies according to its deformation, the activation circuit may set the resonator's resonance frequency to different values by conducting a stronger or lighter control current into heating resistors 22 and 23 to more or less deform resonator 1. Further, the activation  
5 circuit may comprise a control device capable of determining the current resonance frequency of the resonator and of modifying the intensity of the control current to adjust, if necessary, the resonance frequency to exactly have a desired value.

To maintain the beam deformation, and thus the resonator, without  
10 consuming too high a current in heating resistors 22 and 23, the present invention provides, optionally, placing internal electrodes 30 and 31 into beam 2, and placing external electrodes 32 and 33 at the bottom of cavity 10 opposite to internal electrodes 30 and 31. Once the beam has been deformed under the action of the difference in thermal expansion coefficients, it is possible to maintain the  
15 deformation by electrostatic attraction by applying a voltage between internal electrodes 30/31 and external electrodes 32/33, these various electrodes being associated with connection means, not shown.

Internal electrodes 30 and 31 are for example formed of a thin titanium nitride layer (TiN) like heating elements 22 and 23. External electrodes 32  
20 and 33 may be made of aluminum, copper, an alloy of aluminum and copper, or even gold, which has the advantage of not oxidizing in the air. External electrodes 32 and 33 may be portions of one of the upper or of the last interconnect level of an integrated circuit or a separate metal layer.

As a non-limiting example, the dimensions of the different elements  
25 of the device of the present invention are the following:

- thickness of the resonator electrodes: 0.1  $\mu\text{m}$
- thickness of the resonator's piezoelectric layer: 2  $\mu\text{m}$
- resonator width/length: 150 by 150  $\mu\text{m}$
- beam thickness: 2  $\mu\text{m}$

- beam width/length: 200 by 500  $\mu\text{m}$
- aluminum block thickness: 2  $\mu\text{m}$
- thickness of the titanium/aluminum heating resistors: 0.5  $\mu\text{m}$
- width/length of the heating resistors: 200 by 200  $\mu\text{m}^2$
- 5       - thickness of the internal titanium nitride/aluminum internal electrodes: 0.5  $\mu\text{m}$
- thickness of the external gold electrodes: 1  $\mu\text{m}$
- depth of the cavity: 10  $\mu\text{m}$

With such a device, it is for example possible to vary the resonance  
 10 frequency of the resonator by several MHz (for a resonator centered on 2 GHz).

A device according to the present invention comprises lines of access, not shown, to electrodes 4 and 5 of microresonator 1. Such access lines are for example placed on beam 2. To connect upper electrode 5 of the resonator to an access line located on the beam, the device comprises, for example, a thin  
 15 piezoelectric strip laid on beam 2 and juxtaposed to piezoelectric layer 3. The upper electrode extends in a thin conductive strip located above the thin piezoelectric strip. An insulated conductive via crossing the thin piezoelectric strip enables connecting the thin conductive strip to an access line placed on the beam.

Similarly, the device comprises lines of access to heating resistors 22  
 20 and 23 and to internal electrodes 30 and 31. Such access lines may be metal areas placed in, on, or under beam 2.

The resonator electrodes, heating resistors 22 and 23, internal electrodes 30 and 31, and external electrodes 32 and 33 may be connected to connection pads or to elements of an integrated circuit.

25       In the case where the device is a discrete component, the connection pads may be formed on the rear surface of substrate 11, the front surface being that where the resonator is formed.

Whether the device is a discrete component or belongs to an integrated circuit, the various above-mentioned elements may be connected to a

network of connections placed under the substrate or to a rear surface connection pad via vias formed in the substrate and possibly vias formed in the beam in the case where the elements are placed on the beam.

In the case where the device of the present invention belongs to an  
5 integrated circuit, external electrodes 32 and 33 may be portions of the last interconnect level. The external electrodes are then directly connected to the interconnect network of the circuit.

Of course, the present invention is likely to have various alterations, modifications, and improvements which will readily occur to those skilled in the art.  
10 In particular, those skilled in the art will devise other devices of beam deformation by the difference in thermal expansion coefficients. Expandable elements having an expansion coefficient different from that of the beam may be placed around, under or/and on the beam. The expandable elements may possibly be separated from the beam by a dielectric layer. The heating resistors may be placed on the  
15 beam or on the expandable elements.

Such alterations, modifications, and improvements are intended to be part of this disclosure, and are intended to be within the spirit and the scope of the present invention. Accordingly, the foregoing description is by way of example only and is not intended to be limiting. The present invention is limited only as  
20 defined in the following claims and the equivalents thereto.